Chemical Abundances for Sirius using Vega

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Sirius is an excellent target for chemical analysis.

Sirius

is the brightest star in the night sky

high quality spectra have been obtained at ultraviolet and optical wavelengths.

is the primary member of a binary star system

which tightly constrains its mass (2.063 ± 0.023 $M_\odot$).

has been spatially resolved by interferometry

which tightly constrains its angular size (6.04 ± 0.02 mas).

has a precise parallax measurement

which tightly constrains its distance (2.64±0.01 pc) and radius (1.713 ± 0.007$R_\odot$).

has a slow rotation (16 km/s at the equator, 5.5 day rotation period)

so a spherical model is a good approximation.

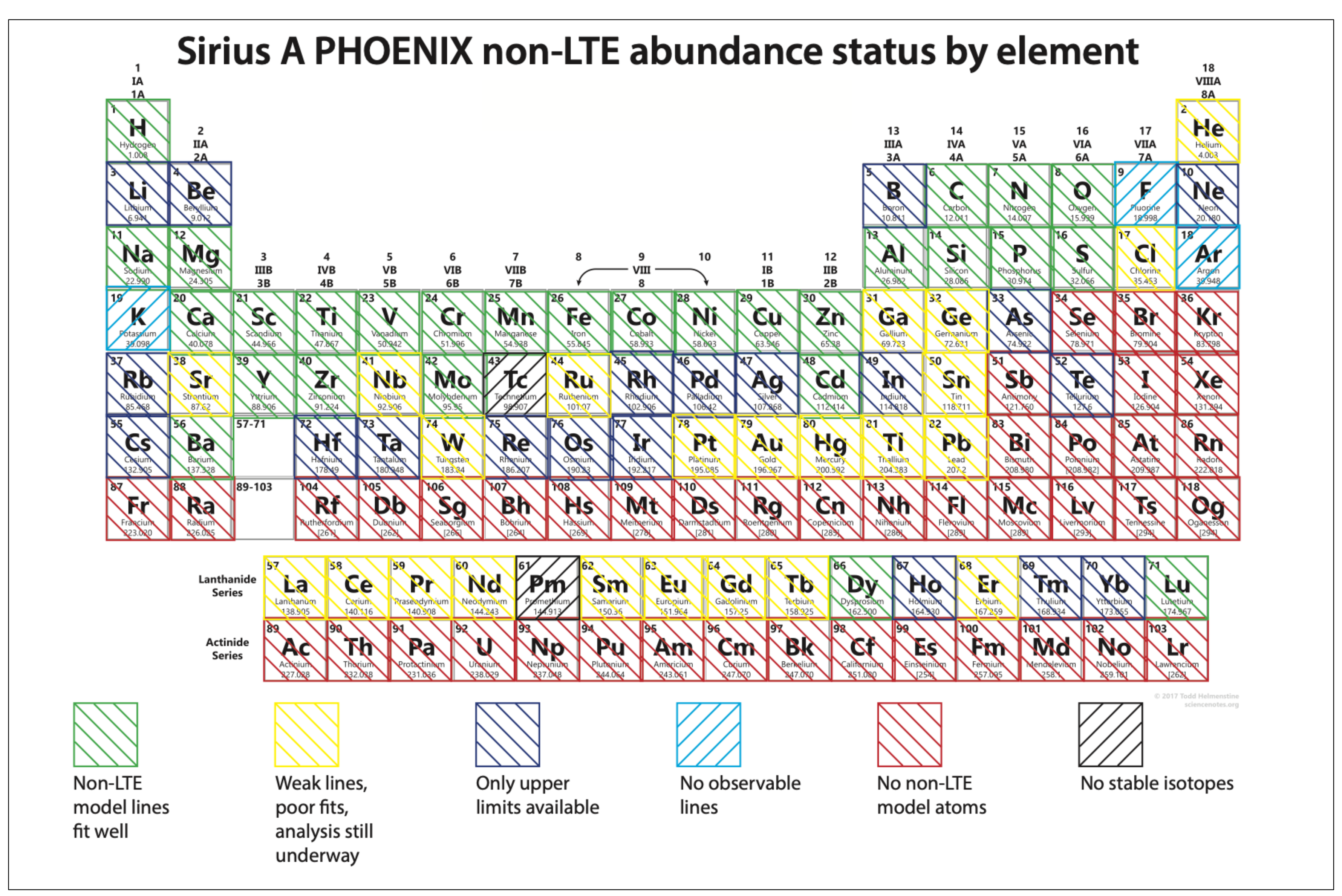
lacks atmospheric convection

so one-dimensional atmosphere models are appropriate.

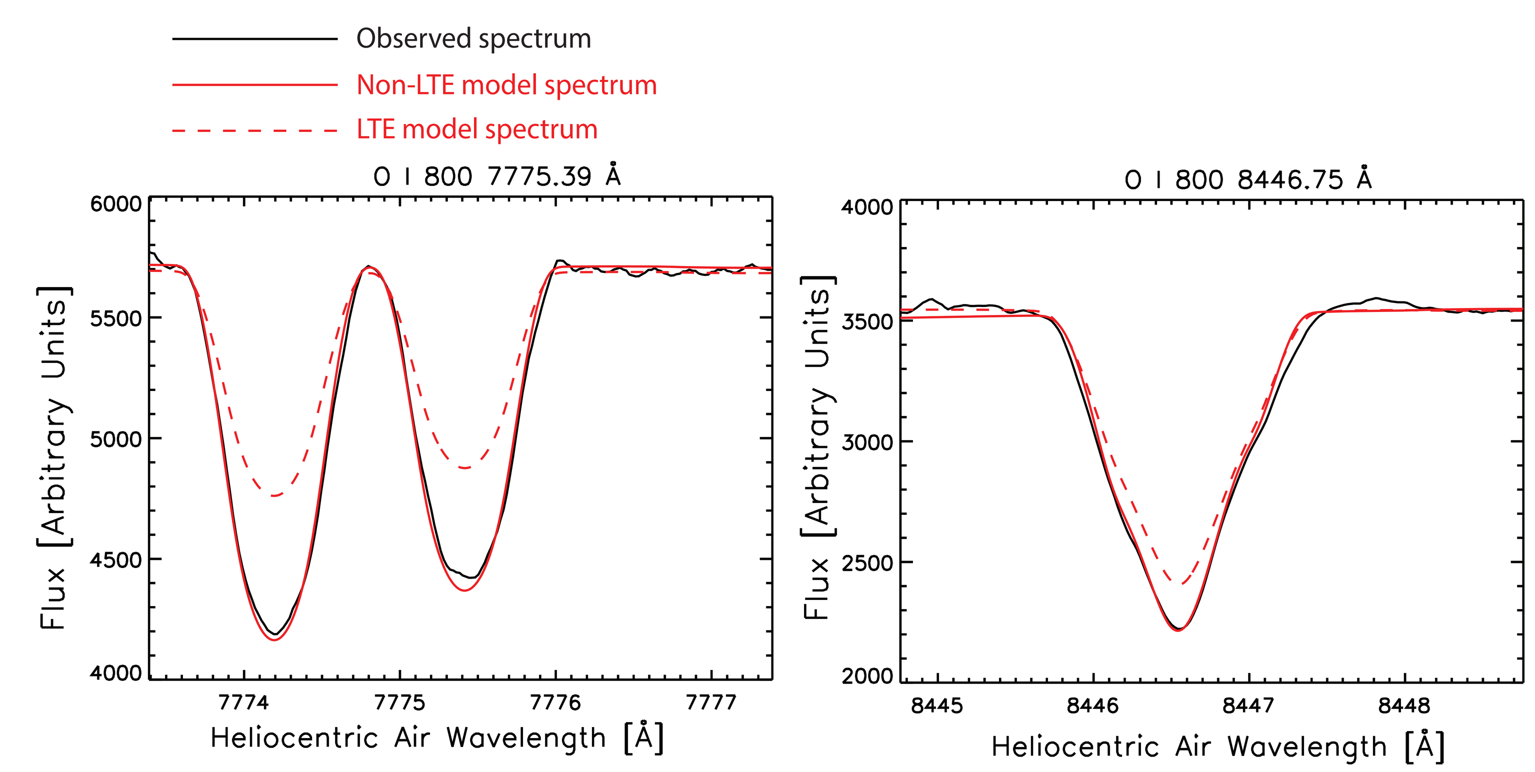
has extensive published chemical abundance analyses in local thermodynamic equilibrium (LTE)

where the excitation and ionization of atoms are governed by Saha-Boltzmann laws, however few non-LTE analyses have been done.

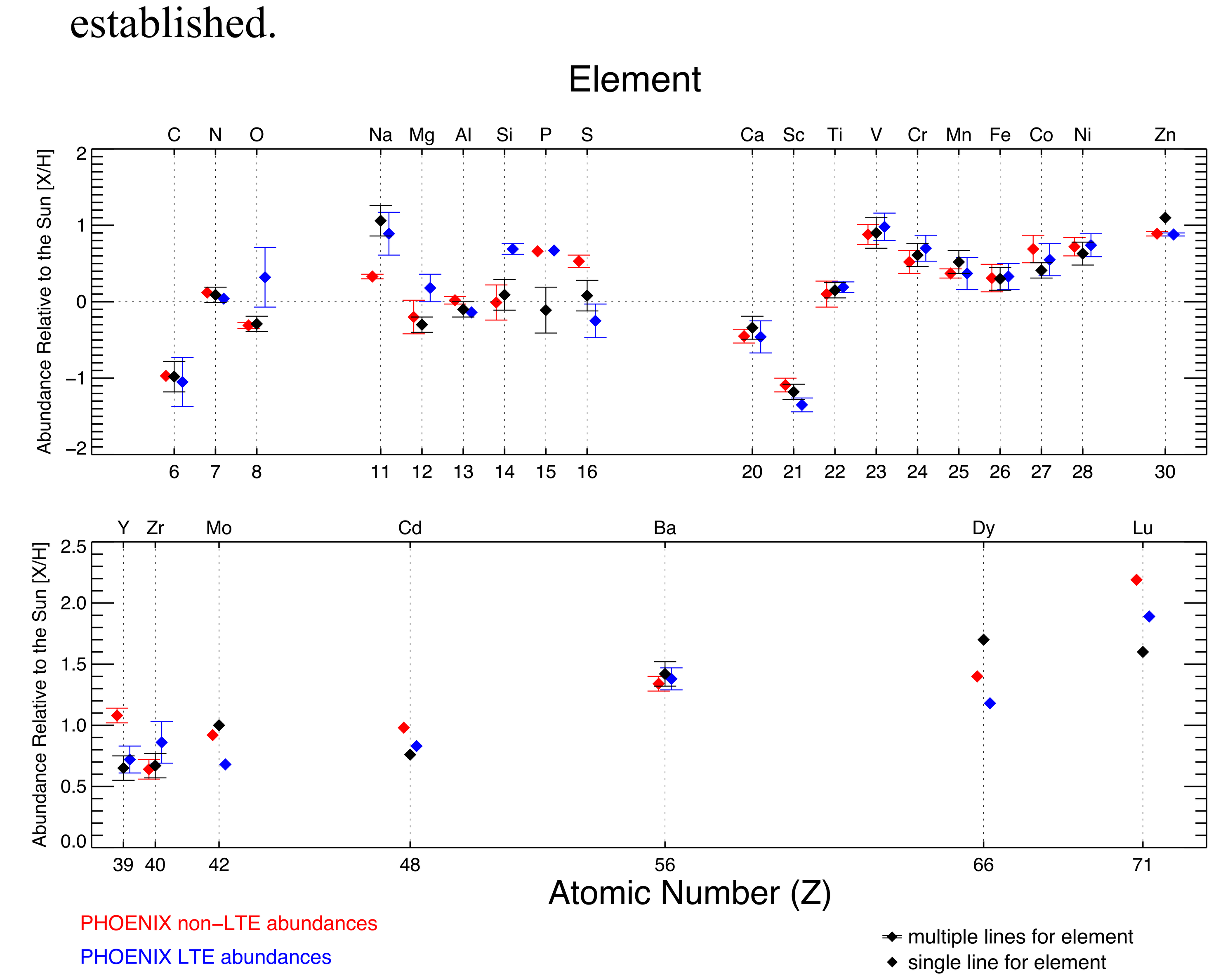
We used the PHOENIX stellar atmosphere code to measure the non-LTE chemical abundances of Sirius using 132 spectral lines of 37 ions from a total of 28 elements.



For the case of neutral oxygen, a non-LTE model yields a consistent abundance for spectral lines 7774 Å, 7777 Å and 8447 Å for the first time.



- Unlike oxygen, these elements show little or no non-LTE effects: C, N, Al, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Zn, Ba. Our abundances agree with previous work (see figure below for a comparison of the abundances of 28 elements to solar values).
- Elements between sodium and sulphur show significant deviations from LTE and from previous work for: NLTE Na (low), NLTE and LTE P (high), NLTE S (high), NLTE Mg (low). Scatter is evident in the figure below.
- Elements Y and Zr are sensitive to non-LTE effects, with a non-LTE yttrium abundance about 2x higher than LTE.
- Remaining elements Mo, Cd, Dy, and Lu do show abundance deviations from previous work, but uncertainties have not been established.



Calculations were performed on "Vega", Embry-Riddle's 3024-core Cray CS400.

A non-LTE model for Sirius by the numbers

- Total atom/ion species in non-LTE: 194
- Total levels in statistical equilibrium: 34,976
- Total non-LTE lines: 635,574
- Total background LTE lines: 1,725,829
- Total wavelength points in spectrum: 5,743,851
- Total CPU time for convergence: 8.5 months (17 hours on 360 cores)
- Total CPU time for spectrum: 180 hours (30 minutes on 360 cores)
- Parameters: Effective Temperature = 9842 K, Surface Gravity log(g) = 4.28, Radius = 1.173 $R_\odot$

References

The mass for Sirius A form the binary orbit is from **Bond, H. E., Schaefer, G. H., Gilliland, R. L., et al. (2017), ApJ, 840, 70**, the measured angular diameter for Sirius A comes from **Davis, J. Ireland, M. J., North, J. R. et al. (2011), PASA, 28, 58** and the parallax of Sirius A is from **van Leeuwen, F. (2007), A&A, 474, 653.**

Motivation for modeling Sirius A and a detailed spectral atlas can be found in **Kurucz, R. L. and Furenlid, I. (1979), SAO, Special Report 387**

Details about the PHOENIX can be found in: **Hauschildt, P. H. and Baron, E. (2010), A&A, 509, A36; Hauschildt, P. H. and Baron, E. (1999), J. Comput. Appl. Math., 109, 41; Hauschildt, P. H. and Baron, E. (2014), A&A, 566, A89.**

Literature LTE abundances are from **Landstreet, J. D. (2011), A&A, 528, A132** and **Cowley, C. R., Ayres, T.R., Castelli, F. et al. (2016), ApJ, 826, 158.** For previous non-LTE abundances see **Lemke, M (1990), A&A, 240, 331** and **Takeda, Y et al. (2011), PASJ, 63, 38**

Solar abundances are from **Asplund, M., et al. (2009), ARAA, 47, 481.**